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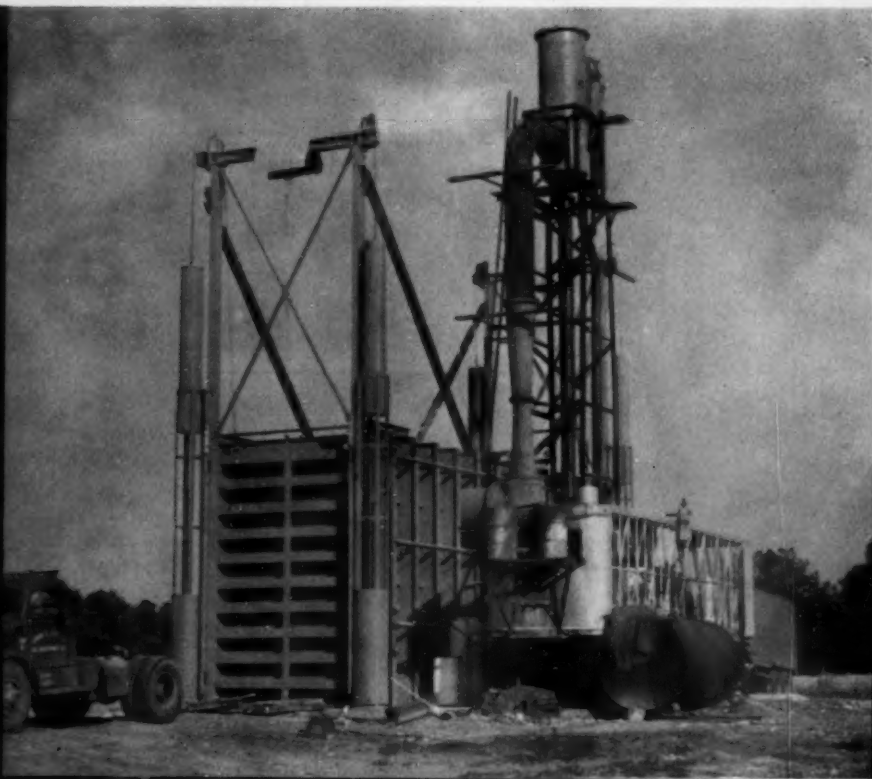

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Vacuum cooling is cooling which is brought about by the extremely rapid evaporation of water from certain vegetables when they are placed in an almost complete vacuum. In 1944 the first patent was issued for the commercial application of this process. The first commercial plant was built at Salinas, California, in 1948, and in that year 34 carloads of lettuce were vacuum cooled. Since that time many new permanent installations have been made in the lettuce and celery producing areas of the West, while movable or semi-movable types of equipment have been developed for use in Eastern areas, which have shorter growing seasons. Most lettuce in this country is now vacuum cooled. Lesser amounts of certain other vegetables are also processed in this way.

Basic Principles

The equipment for vacuum cooling consists basically of strong walled chambers capable of resisting great external pressure for holding the vegetables, and pumps or steam jet assemblies with appropriate condensers capable of producing and maintaining high vacuums.

In the range of temperatures and atmospheric pressures in which people ordinarily live, (around 70° F. and 14.7 pounds per square inch) evaporation of water is much too slow to have any use in cooling large quantities of vegetables. The rate of evaporation is, however, tremendously greater in a vacuum or at high temperatures. When evaporation becomes so rapid that it takes place almost explosively all through the body of the liquid as well as at

Cover: Steam jet vacuum cooler in Oswego County, New York. This cooler is capable of cooling a trailer load at one time.

the surface, we say that the liquid is boiling. At ordinary atmospheric pressures water boils only when it is very hot, that is, at about 212° F. However, if the pressure on the surface of the water is reduced from the normal, 14.7 pounds per square inch to ½ pound per square inch, it boils at 80° F.; and at .089 of a pound, it boils at 32° F.

The boiling process, or rapid evaporation, however, requires a certain amount of heat or energy whether the process takes place at 212° F. or at 32° F. This energy, or heat, is necessary just to change water from the liquid state to the vaporous state without any change in temperature. When a vegetable is placed under vacuum, the field heat and the heat of its own biological processes are used to produce the evaporation within its own tissues. As the heat is utilized to change water to vapor, the vegetable becomes increasingly colder. Thus when a vacuum of .089 pounds per square inch is maintained, water boils out of the vegetable until the heat is used and the temperature drops to 32° F. It is, in fact, easily possible to freeze a vegetable if the pressure is allowed to drop much below .089 pounds per square inch.

In vacuum precooling of vegetables for the fresh market, such freezing must, of course, be carefully avoided. Some foods and medical supplies are, however, intentionally frozen in commercial vacuum cooling processes. The various pressures and temperatures at which water boils are shown in table 1.

The actual cold production, or heat removal, takes place at what-

Table 1. Temperatures at Which Water Boils under Various Pressures

Pressure on System			Temperature at Which Water Boils
Pounds per square inch	Inches of mercury*	Millimeters of mercury*	Degrees (Fahrenheit)
0.035	.07	1.8	10.00
0.089	.18	4.6	32.00
0.098	.20	5.1	34.55
0.196	.40	10.1	52.67
0.294	.60	15.2	72.35
1.000	2.04	51.7	101.76
7.000	14.25	362.0	176.85
14.697†	29.92†	760.0†	212.00

Source; Data calculated from Hodgman, Charles D. *Handbook of Chemistry and Physics*, Chemical Rubber Publishing Company, 1957.

*Pressure is often expressed in terms of inches or millimeters of mercury rather than in pounds per square inch.

†Normal atmospheric pressure at sea level.

ever points on or in the product from which liquid water can vaporize directly into the vacuum. Consequently, if a product has much surface exposed to spaces that connect directly to the vacuum pump, that is, are not separated from it by any liquid or solid barrier, cooling can take place extremely rapidly. Experimentally, heads of lettuce have been cooled from 77° F. to 32° F. in 5 minutes and this cooling is about as great in the inner leaves as in the outer.[1] Commercially, the time required may range from 20 to 50 minutes, but with lettuce the length of these periods is determined by the capacity and efficiency of the equipment, not by the inherent characteristics of the product or its container.

The amount of cooling that is obtained by the evaporation of one pound of water is very great, enough to cool more than 1000 other pounds of water or more than 1000 pounds of lettuce one degree Fahrenheit.

On the other hand, great pump capacity is required to vaporize a single pound of water from a product at 32° F. A pound of water in vapor form at this temperature occupies 3301 cubic feet.[2] (In liquid form at 32° F. one pound of water occupies only 1/62 of one cubic foot). So, to bring the temperature of 1000 pounds of lettuce down just one degree, from 33 to 32° F. would require the pump to remove at least 3300 cubic feet of vapor.

The need for equipment of large capacity may be shown also by calculations on the amount of heat removed in the short periods of cooling which are characteristic of the vacuum method. To cool the lettuce in four hundred 40-pound boxes forty degrees from 73° F. to 33° F. in 30 minutes requires the removal of 614,400 British thermal units in 30 minutes or 102.4 tons of refrigeration.[3] This is a considerable amount of refrigeration in comparison, for example, with a ten-cubic-foot household refrigerator, which has a capacity of 1/5 of a ton of refrigeration.

If all the water which is vaporized to produce cooling comes from the vegetable itself, why doesn't excessive wilting occur? In practice, wilting has not been a serious problem. Experimental evi-

[1]Dewey, D. H. Air Blast and Vacuum Cooling of Vegetables and Fruits. Thesis for Ph.D., Cornell Univ. 1950.

[2]Dewey, D. H. "Evaporative Cooling of Fruits and Vegetables." *Refrigerating Engineering.* 60:1281–1283. 1952.

[3]Lettuce, which is mostly water, has a specific heat of .96. This means that 96% as much heat must be removed to lower the temperature of a pound of lettuce one degree as must be removed to lower the temperature of a pound of water the same amount. So, from the standpoint of cooling, the 16,000 pounds of lettuce are equivalent to 15,360 pounds of water. To cool 15,360 pounds of water 40 degrees F. would require 15,360 times 40 or 614,400 British thermal units. A British thermal unit is the amount of heat required to raise (or the amount of heat removed to lower) the temperature of one pound of water one degree F. Also, a ton of refrigeration, in the sense used by engineers, is a rate of heat removal equal to 6,000 British thermal units per half hour.

dence indicates that the amount of water removed from leafy vegetables ranges from 1.0 to 4.7% by weight, with an average of about 2.5%.[4] It is evidently because this loss occurs about equally from all parts of the produce that wilting is generally not apparent.

Of course, when a vegetable is under a very high vacuum, no air is in contact with it. One might think that, in the absence of oxygen, the living tissues of which it is composed would suffocate. In commercial practices and in experiments it has been shown, however, that no suffocation occurs in the ten minutes or longer that the product is almost completely deprived of oxygen. In fact, in tests where lettuce was vacuum cooled *for eight hours* and then stored for three weeks at 38° F., no suffocation injury was found.[5]

Types of Coolers

Mechanically all vacuum coolers consist of three essential parts. The first is a tube or chamber for holding the produce. The second essential part is some type of vacuum-producing mechanism. The ones presently in operation vary considerably in design depending upon whether they are operated by steam, electric, or diesel power. The third essential part is a condenser for changing steam or vapor back into liquid water. When steam or vapor is changed back into water it gives up the heat which it took originally from the vegetables. At the same time, in changing back to liquid water from vapor, it is again reduced in volume from 3301 cubic feet per pound to 1/62 of one cubic foot per pound. Hence, the condenser both disposes of the heat and helps create the vacuum.

Construction of Tube or Chamber for Holding Produce

The tube or chamber for holding the produce must have walls which will withstand external pressures of one atmosphere, that is, approximately 14.7 pounds per square inch. They must also be constructed so that their openings can be tightly sealed. Getting a tight seal is not especially difficult. As soon as a little vacuum is induced, the doors press tightly against their seats.

Tubes are of various sizes. Figure 1 shows a pair of tubes capable of holding three loaded railroad refrigerator cars. This would represent from 1500 to 1800 standard lettuce boxes. Figure 2 shows the type of tubes more commonly found in the permanent installations of the South and West. These tubes are in batteries of three or four. They are equipped usually with a single long dolly on which the

[4] Friedman, B. A. "Vacuum Cooling of Vegetables and Fruits." *Pre-Pack-Age,* 5: 18–20, 22, 25. 1952.

[5] Unpublished data of G. L. Rygg and D. H. Dewey, quoted by Friedman, B. A. "Vacuum Cooling of Vegetables and Fruits." *Pre-Pack-Age,* 5:18–20, 22, 25. 1952.

Figure 1. **Large vacuum chambers at Salinas, California. The one at the left holds two loaded refrigerator cars, and the one on the right holds a single car.**

produce is placed, and it is pushed into the tube in one operation. These tubes usually hold about a half car load. Figure 3 shows a small transportable tube which holds only 250 standard lettuce boxes. The tube in the cover illustration is capable of holding a truck trailer, which generally represents a load of 400 to 500 lettuce boxes.

Types of Vacuum Pump and Condenser Assemblies

The two types of vacuum-producing equipment commonly used are steam-jet systems and rotary mechanical pump systems.

Steam-Jet Systems

The first commercial cooler used for vegetables was of the steam-jet type. Such coolers are generally of the three-stage type, that is, the vacuum is built up by three steam-jets connected in series. A simplified design for such a system is shown in figure 4. It consists of a vacuum chamber for holding the produce; a boiler (not shown) for supplying steam to one large ejector or jet, labeled the primary jet in figure 4; and two smaller ejectors or jets, labeled secondary and the third jets. Each ejector is composed of one or more steam nozzles or jets and a tube of particular shape, called a diffuser, into which the nozzles discharge. Steam under pressure shoots out of the jets and through the diffuser of the primary ejector with such velocity that it sucks along with it most of the air and water vapor from the vacuum chamber. Such an ejector if it were discharging directly into the outside air could be expected to reduce the pressure in the vacuum chamber from 14.7 pounds per

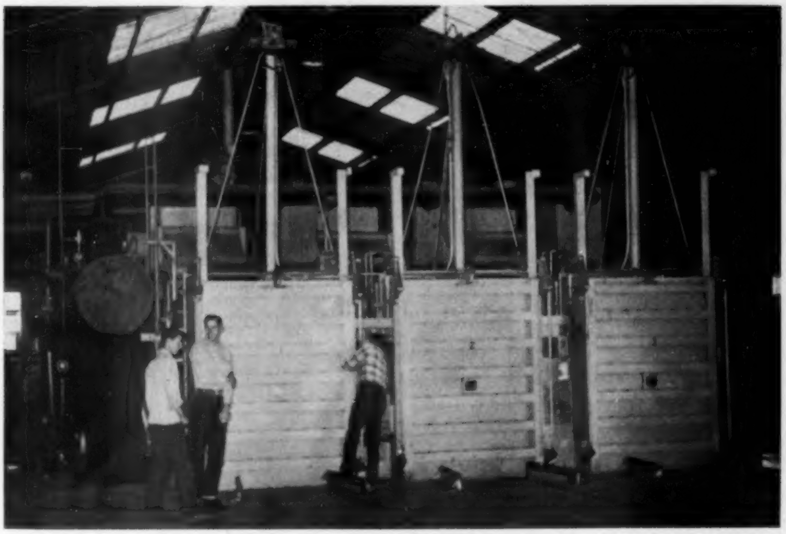

Figure 2. A three-chamber permanently installed vacuum cooler. These chambers, though not as numerous as in many plants, are typical of most installations found in the South and West.

Figure 3. Portable vacuum cooler, with tube on the left and ice condenser tank on the right.

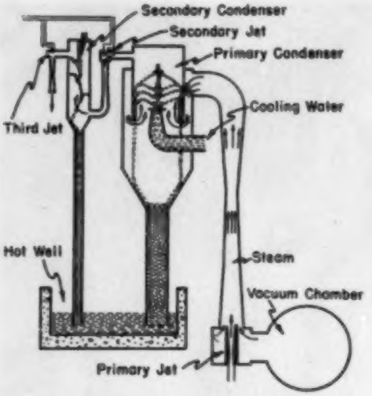

Figure 4. **Diagrammatic sketch of a steam-jet vacuum cooling system.**

square inch to perhaps 0.7 of a pound. However, at this pressure water boils at too high a temperature to effect much cooling, and in addition, large quantities of water in the form of steam would be lost. Therefore, this primary ejector is discharged into a large barometric condenser[6] called the primary condenser in figure 4. Large quantities of cold water are pumped through the condensers, which change the steam from the jets back into water and also change the vapor from the produce into water. This in itself helps create a vacuum, but to get the additional needed vacuum, the primary condenser is connected to a secondary jet and a secondary condenser. This additional suction from the secondary jet and condenser generally lowers the vacuum in the primary condenser down to about 0.1 pounds per square inch. To increase the efficiency of the secondary condenser, it is connected to a third jet which discharges directly into atmosphere. Through this system a high vacuum can be attained.

To operate a steam system, fairly large quantities of water must be available, or some means for storing large quantities must be provided. The efficiency of the condensers are somewhat dependent upon the temperature of the cooling water which flows through them, since part of their function is to conduct off the heat removed from the produce as well as the heat from the steam. The steam-operated tube shown on the cover has an intake of 75,000 gallons per hour from the Oswego River. The transportable steam cooler shown in figure 5 requires around 600 gallons per minute for cooling. To obtain this cooling water, an air condenser is located just forward of the boiler to cool the water for re-use. Other transportable steam types like this have large canvas reservoirs to collect and hold a large quantity of water, which can be cooled naturally.

Mechanical Vacuum Systems

Mechanical vacuum pumps are used in the very largest vacuum cooling installations, such as that

[6]Barometric condensers are condensers in which, although connected with the outer atmosphere, a partial vacuum can be maintained. This is possible because they are equipped with a long tail pipe in which a column of water stands. Water can flow out of the condenser through this pipe into a hot well even though there is a vacuum above.

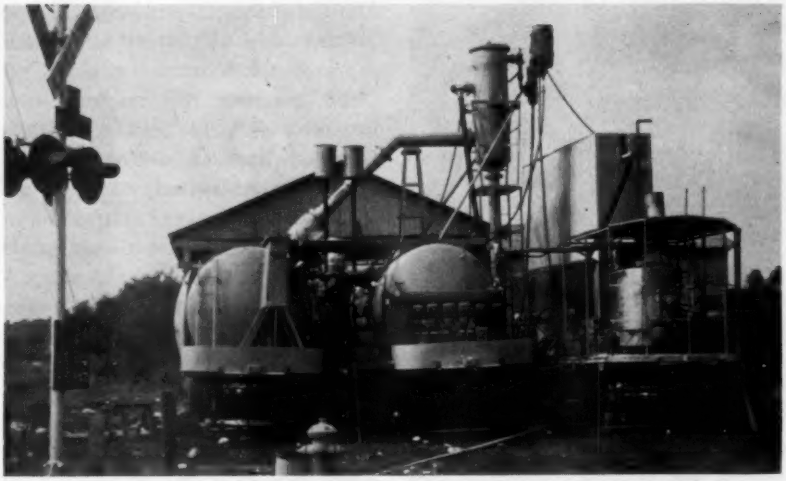

Figure 5. **A completely portable jet vacuum cooler. There are two tubes for holding the produce; one on the left-hand trailer and one on the middle trailer. The boiler and air condenser are mounted on the right-hand trailer. The primary condenser is upright between the boiler and tubes.**

illustrated in figure 1, as well as in some of the smallest as shown in figure 3. The larger plants use a type of pump of which figure 6 is a simplified cross-section. The heart of the apparatus is two large rotors turning on the same shaft, at 600 revolutions per minute, in separate stationary cylinders. The axes of the rotors are below the central axes of the cylinders, so that the rotors are in contact with the bottoms of the cylinders, but not with the other parts of them. In the rotors, however, are movable blades held in contact with the cylinder walls by centrifugal force. At the lower side of the cylinder these blades are forced back completely into their respective slots, but at all

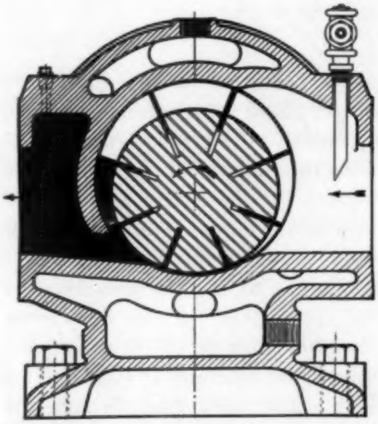

Figure 6. **Cross section of a portion of a mechanical rotary vacuum pump. The intake vestibule is shown in white, while the exhaust vestibule is shown in black. Courtesy of the Fuller Company, Catasauqua, Pennsylvania.** ***See text for explanation.***

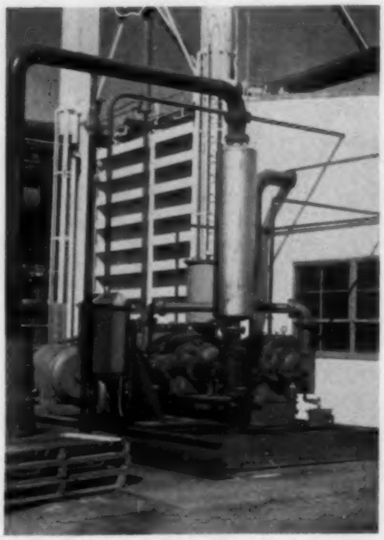

Figure 7. **Two-stage centrifugal vacuum pump used as an auxillary in large cooling plant in Salinas, California.**

other positions of the rotor, the blades alone form contact with the cylinder walls. Thus moving chambers the length of the rotor are formed for the intake and exhaustion of the vapors. The intake vestibule, shown in white in figure 6, is connected to the chamber holding the vegetables, or to any other chamber that is to be evacuated. When the machine is running, air and water vapor pass through the intake ports into the spaces formed by the movable blades. As the rotor turns and the chambers approach the exhaust vestibule, shown in figure 6, the air and vapor are considerably compressed. This compression aids in their expulsion. Figure 7 shows one of these pumps with the motor and exhaust pipe.

To get the vacuum required, both cylinders are connected directly to the chamber holding the vegetables in the initial stages of an operation. However, as the chamber is evacuated and the pressure within the chamber falls to about 5 millimeters of mercury, the valves are changed so that the smaller of the two cylinders draws directly from the exhaust side of the larger cylinder. In this way, for the final stages of evacuation, the two cylinders, operating in series, are used to obtain the necessary suction.

Between the vacuum chamber and the pumps, there are very cold refrigeration coils which act as condensers, freezing out almost all the water vapor before it can reach the pumps. These coils are cooled by direct-expansion ammonia refrigerating systems. Presumably they are defrosted after completion of the cooling of each batch of vegetables.

Rotary mechanical vacuum pumps used in smaller installations may be of a design somewhat different from that described. However, the effect is much the same. Also, where mechanical ammonia refrigeration is not feasible for moisture condensation and consequent protection of the pump against excessive heating, transportable ice condensers are used. Figure 3 shows equipment in which

the pump is operated by a diesel motor, shown on the left, and water vaporized from the produce is reliquified by an ice condenser, shown at the right. The condenser, in this case, is the same size as the vacuum chamber and can be mounted on a truck trailer. In operation, the condenser tank is filled with ice, usually in 100-pound cakes. The vapor is drawn through the tank, where it comes in direct contact with the ice. The more ice and the more surface available for the water vapor to condense upon, the more efficient the cooling operation. Between runs, the tank is drained of excess water and more ice is added. A considerable amount of ice is required to operate these coolers at maximum speed.[7] Such a cooler cannot, of course, actually cool to 32° F. At 32° it would be vaporizing rather than condensing water around the ice.

Actual Systems in Use

The first commercial vacuum precoolers for fresh vegetables were of the steam-jet type. These original installations still apparently operate with very satisfactory efficiency. Perhaps one disadvantage with them is their need for especially large condensers and either large quantities of cool water or facilities for recooling that which flows through the condensers. On the cover is shown a partially transportable steam vacuum cooler located in Oswego County, N. Y. This is situated on the Oswego River, from which the operators are able to draw 75,000 gallons of water per hour.

Although, as has been indicated, rotary pump installations also require condensers, these are only for condensing water vapor from the vegetables, whereas with the steam jets, considerable amounts of steam from the boilers have to be condensed also.

In most areas in the West and the South, the harvesting season is long enough and the daily production great enough to justify expenditures for large permanent installations. In the East, however, there has been a tendency for operators to build smaller equipment from which the more expensive components can be moved from one area to another as each area comes into production. The vacuum chamber of the installation shown on the cover is permanent, but the steam boiler and controls are mounted on a trailer. The ejectors and condensers are attached to the chamber, but can be dismounted in a

[7]According to the calculations shown in the note at the bottom of page 4 614,400 British thermal units are required to be removed from four hundred 40-pound boxes of lettuce to lower the temperature 40 degrees. Since the melting of one pound of ice absorbs 144 British thermal units, 4267 pounds of ice would be required if all the water were condensed. Actually the maximum capacity of the cooler in figure 3 was 250 boxes. So the corresponding ice requirement would be 2666 pounds per batch.

day or two. In this way one set of steam equipment can service several permanent tubes located in regions where production occurs at different seasons. The ownership of the vacuum chamber may be different from the ownership of the boiler and jets. Figure 5 shows a completely transportable steam-operated cooler. There are two vacuum chambers, each mounted on its own trailer, and a boiler and a large heat exchanger for cooling condenser water mounted on another. The boilers of most of these mobile coolers are express types capable of developing steam pressures of 150 pounds per square inch in 3 to 4 minutes. This type of equipment can be used anywhere that large trailer-trucks can go and there is a sufficient supply of water.

The very large coolers shown in figure 1 are evacuated by five two-stage rotary mechanical pump units. The product before cooling is packed in cartons, stapled shut but not sealed. In this case the cartons are loaded in the railroad car ready for shipment East. For the vacuum to be effective, it is only necessary that the car doors on one side be left open.

Adaptation of Different Vegetables for Vacuum Cooling

As has been pointed out, a sufficient vacuum can cause water to boil out from any surface of a vegetable which is connected directly through air or vacuum spaces with the vacuum pump. In this sense, the surface of a head of lettuce is not just that surface which is visible from the outside. It includes all the surfaces of all the leaves of the head. Water can boil out of a leaf close to the core and the vapor molecules will quickly follow the vacuum gradient to space outside the head and outside the carton in which the product is packed. Putting the head in a film bag does not appreciably retard cooling if the bag is not completely sealed. As a matter of fact, if the bag is sealed, it will burst under high vacuum.

Vegetables with much surface in relation to volume or weight cool best. The situation which leads to quick cooling is the one where all of the tissue is not far from a surface from which vaporization is taking place. As has been explained, when molecules of water evaporate, the cooling effect occurs first right at the point of vaporization. Such cooling occurs almost instantly. The cooling of tissues back away from a surface takes place only by conduction of heat to the surface. Conduction is a relatively slow process through the tissue of green vegetables. So, the farther a tissue is away from a surface the much more slowly it cools.

Another essential for satisfactory vacuum cooling is that the exposed surfaces be ones from which water can vaporize easily. For example,

Table 2. Effectiveness of Vacuum-Cooling Vegetables with Large Surface Area-to-Volume Ratio*

Commodity	Container	Duration of vacuum cycle	Temperature of commodity at: Beginning of cycle	Temperature of commodity at: End of cycle
		Minutes	°F.	°F.
Brussel sprouts	Quart cup	20	68	38
Cabbage	None	20	68	40
Coleslaw	Cellophane bag	20	67	34
Coleslaw	Cellophane bag	18	65	32–36
Endive	Crate	20	68	36
Endive, Belgian	Bundle	14	67	40
Escarole	Crate	20	68	36
Lettuce	Crate	55	60–70	32–33
Lettuce	Crate	20	72	32
Lettuce	Cellophane wrap	10	75	34
Lettuce	Carton	13	71	36
Lettuce	Carton	13	69	34
Parsley	Crate	20	68	34
Salad mix	Cellophane bag	20	65	35
Soup mix	Cellophane bag	20	62	34
Spinach	Cellophane bag	20	65	34
Spinach	Cellophane bag	20	66	35
Spinach	Bushel basket	10	67	37

*Tables 2,3,4 and 6 in this publication taken from B.A. Friedman and W.A. Radspinner, Agricultural Marketing Service, Publication 107, April 1956.

the skins of potatoes are impregnated with a material called suberin, which strongly resists the passage of water or water vapor. When little water reaches the surface of a vegetable, this surface can never be effectively cooled by vacuum.

Lettuce has been the outstanding vegetable to be vacuum cooled. Other completely leafy vegetables, like spinach, endive or escarole, or parsley can be cooled just as well as lettuce or even better. Cabbage and Brussels sprouts seem to cool a little more slowly in vacuum than the others, as is shown in table 2. Perhaps this is because the leaves are waxy and resistant to dehydration or, especially in the case of cabbage, because the heads are so

Table 3. Effectiveness of Vacuum-Cooling Vegetables with Medium Surface Area-to-Volume Ratio

Commodity	Container	Duration of vacuum cycle	Temperature of commodity at Beginning of cycle	Temperature of commodity at End of cycle
		Minutes	°F.	°F.
Artichoke	Crate	16	66	50
Asparagus*	Bunch	10	64	36
Beans, snap	Hamper	20	80	60
Beans, snap	Hamper	12	69	45
Beans, snap	Cellophane bag	14	70	43
Broccoli	Wirebound crate	20	65	45
Broccoli	Crate	13	67	44
Cauliflower	Crate	20	76	44
Cauliflower	Crate	13	62	46
Celery	Cellophane	20	68	42
Celery	Cellophane bag	20	66	47
Celery	Crate	13	70	47
Celery	Crate	13	77	53
Corn, sweet, husked*	Cellophane tray	10	59	36
Corn, sweet, husked*	Cellophane tray	10	75	39
Corn, sweet, unhusked	Crate	20	83	43
Leeks	Wirebound crate	20	68	36–40
Mushrooms	Basket (9 lb.)	20	67	39
Mushrooms	Basket (9 lb.)	16	66	35
Mushrooms	Basket (9 lb.)	15	70	45
Mushrooms	Carton (3 lb.)	15	69	46
Mushrooms	Prepackaged	15	68	43
Mushrooms	Prepackaged	15	70	45

*Vacuum was drawn with experimental equipment to 29.79 inches mercury at which point water boils at 25° F. Ice formed on spears of asparagus, but none on sweet corn.

compact that there are really no open channels from some of the inter-leaf spaces to the outside.

These other leafy vegetables are not so generally cooled as lettuce, because the volume of several of them is not large enough to justify vacuum installations. Cabbage, on the other hand, generally keeps well without the shippers' going to much special expense to cool it or keep it cool.

A second group of vegetables are moderately hard to vacuum cool.

Table 4. Effectiveness of Vacuum-Cooling Some Vegetables and Fruits with Small Surface Area-to-Volume Ratio*

Commodity	Container	Duration of vacuum cycle	Temperature of commodity at: Beginning of cycle	Temperature of commodity at: End of cycle
		Minutes	°F.	°F.
Carrots, roots	None	20	66	60
Cucumbers	Baskets	20	78	73
Peppers, bell	Hamper	20	80	50
Potatoes, intact	None	30	65	57
Potatoes, skinned	None	30	65	45
Tomatoes	Cellophane tray	20	73	67
Tomatoes	Cellophane tray	20	77	71

*B.A. Friedman and W.A. Radspinner. U.S.D.A., Agricultural Marketing Service—107, Washington 25, D.C.

These include celery and sweet corn, which, nevertheless, are being commercially vacuum-cooled to a considerable extent. Parts of all these vegetables are relatively large solid masses of tissue. The leaves of celery would be expected to cool very rapidly, of course, but centers of the fleshy petioles,[8] which make up most of the weight, must lose their heat by conduction outward a quarter of an inch or more to the nearest surface when placed under vacuum. The hearts of the celery and the thick stems of apical heads of broccoli present even greater difficulties. Relative cooling rates of this group of vegetables are presented in table 3.

Hard-to-cool vegetables include ones which are large masses of tissue with relatively little surface areas. In addition, ones like potatoes, tomatoes, peppers, cucumbers and carrots are comparatively well protected against moisture loss, as they have surfaces that resist the outward passage of moisture or moisture vapor. Data on these vegetables appear in Table 4.[9]

For cases where relatively little moisture can be drawn out of the vegetable to produce cooling, it has been suggested that the product be wetted before being put in the vacuum. The difficulty remains, however, with the crops of the third group that they just don't have enough surface. In actual experiments wetting has not produced enough additional chilling to make commercial vacuum cooling look

[8] Petioles are called "branches" in the vegetable industry and in the grade standards.

[9] B. A. Friedman and W. A. Radspinner. "Vacuum-Cooling Fresh Vegetables and Fruits". U.S.D.A., Agr. Mktg. Service—107, Washington 25, D.C.

Table 5. Average Temperatures and Weight Losses of Wet and Dry Sweet Corn Vacuum Cooled in Laboratory Unit at Belle Glade, Florida*

Test No.	Dry† or Wet	Units Tested	Containers or Ears	Time in Vacuum	Corn Temperature (Cob) Before	After	Decrease	Weight Loss
		No.		Min.	°F	°F	°F	%
1	Dry	2	Fiberboard Cartons	18	78	38	40	—
2	Dry	2	Fiberboard Cartons	30	84	38	46	—
3	Dry	1	Wirebound Crate	25	83	40	43	—
3	Dry	1	Fiberboard Carton	25	84	36	48	—
4	Wet	1	Wirebound Crate	40	82	33	49	—
4	Dry	1	Wirebound Crate	40	84	32	52	—
5	Wet	60	Ears	40	81	35	46	2.7
5	Dry	60	Ears	40	90	34	56	5.5
6	Wet	36	Ears	40	84	38	46	0
6	Dry	36	Ears	40	86	38	48	6.1

*Data from R.K. Showalter and B.D. Thompson. "Vacuum Cooling of Florida Vegetables." *Proceedings of the Florida State Horticultural Society*, 69:133–135, 1956.

†Treatment prior to vacuum cooling.

promising for them. With some members of the intermediate group, where the true advantages of vacuum over other methods of precooling are somewhat uncertain without the addition of surface moisture, the pre-wetting of the product may have commercial significance. Experimental data on celery have, on the average, shown a slight benefit. In one test with one variety of sweet corn in the husk, the wetted lot cooled from 68° F. to 34.3° F., while the dry lot, starting at the same temperature, cooled to 36.5° F.[10] With another variety; however, the unmoistened lot cooled slightly more rapidly. The cooling in both treatments, in this case, was fairly good, from 11° to 37° or 38° F. in 28 minutes.

Since this original work, additional experimental results[11] shown in Table 5 have indicated that sweet corn can be cooled commercially by vacuum. The best results with this method, however, required that the ears be wetted with water of ordinary temperature prior to vacuum cooling and then re-wetted with ice water after

[10]Data on sweet corn and broccoli are from D. H. Dewey. Air-blast and Vacuum Cooling of Vegetables and Fruits. Thesis for Ph.D., Cornell Univ. 1950.

[11]Data from R. K. Showalter and B. D. Thompson. Vacuum Cooling of Florida Vegetables. Proceedings of the Florida State Horticultural Society, 69:133–135, 1956.

Table 6. The Effect of the Use of Vacuum Cooling and Ice upon the Salability of Prepackaged Spinach Held at 73° to 76° F. for 44 Hours*

Treatment	No. of bags	Salability		
		Salable	Barely salable	Unsalable
Vacuum-cooled; iced	24	12	9	3
Vacuum-cooled; not iced	24	1	9	14
Not vacuum-cooled; iced	24	4	4	16
Not vacuum-cooled; not iced	24	0	7	17

*Table taken from B.A. Friedman. "Vacuum Cooling of Prepackaged Spinach, Cole Slaw and Mixed Salad." *Proceedings of the American Society for Horticultural Science*, 58:279–287, 1951.

cooling. When this is done, corn cooled by vacuum and then held for several days with top icing actually had greater succulence and less denting of the kernels than corn cooled by a standard hydrocooling method.[12] Broccoli, on the other hand, showed great benefits from pre-wetting alone. Wet and dry lots had initial temperatures of about 69° F. Subjected to 17 minutes of vacuum treatment, the temperature in the stems of the dry lot dropped to 39.7° F., whereas the corresponding value for the moistened lot was 32.9° F.

The tendency with moderately hard-to-cool vegetables is to leave them in the vacuum longer to get all possible additional cooling. If this is done, there is likely to be wilting or more serious drying injury of exposed tissues. Prewetting naturally tends to overcome this difficulty, as has been shown experimentally.

[12]Corn was hydrocooled for 25 minutes by passing it through a machine in which the crate was partially submerged in ice-water and partially sprayed with ice-water. Information is from R. K. Showalter. "Effect of Wetting and Top Icing Upon the Quality of Vacuum Cooled and Hydrocooled Sweet Corn." Proc. Florida State Hort. Society 70:1957.

Effect of Container

As has been mentioned, any commodity which can be cooled readily by vacuum when not packaged, can be cooled as readily when packaged. The container has no effect provided it is not sealed. The validity of this conclusion has been established experimentally as well as by results of commercial practice. Tests with prepackaged spinach and cole slaw have shown that these commodities can be cooled more rapidly and efficiently by vacuum than by placing them in refrigerated storage rooms. Vacuum precooled spinach, when properly refrigerated afterward, had excellent shelf-life, as indicated in table 6.

Advantages of Vacuum Cooling and Vacuum Precooled Products

Vacuum cooling has been spectacularly successful with head lettuce. It seems appropriate, therefore, to consider first the advantages it has had with this one product. The rapid acceptance of the practice with lettuce is attributable in part to the rapidity and efficiency with which the cooling operation is accomplished and in part to accompanying economies and conveniences in handling this crop. Compared with shed-packing and cooling by package icing—the system which it replaced—field packing and vacuum cooling are considerably more economical. This is because less handling is required and shoveling ice into crates has been eliminated. Cheaper fibre board cartons have, for the most part, replaced the wooden crate. Freight cars and trucks can carry a greater load of lettuce since container ice is no longer essential. Bunker ice has proven sufficient to hold down the temperatures of vacuum cooled lettuce. Furthermore the package ice squeezing against the heads frequently caused more bruising and breakage of outer leaves than is found in the dry package. A special additional advantage is that workmen and salesmen who have to handle the wholesale containers much prefer the dry, comparatively light-weight cartons to the heavy crates which were always dripping water. On the other hand, dry pack lettuce often does show some wilting of outer leaves, but this defect has not been regarded as serious. Wholesale market acceptance of vacuum-cooled lettuce has been excellent.

The advantages of dry-pack vacuum-cooled celery, sweet corn and broccoli over the corresponding hydrocooled or packaged-iced product are somewhat less certain than those described for lettuce. But celery and sweet corn are commonly field-packed even when the vacuum process is not used. It might be well to point out the fact that if a vegetable has been cooled by vacuum (or by any other method) it is not always a guarantee that it has been adequately cooled.

For prepackaged leafy vegetables and salad mixes, cooling after the packaging operation is an extremely effective and ideally convenient method. The fact that such cooling of prepackaged products is not widely practiced is probably due to the initial expense of the vacuum equipment and to a lack of information on the process.

Designers and Manufacturers of Vacuum Cooling Systems and Their Parts

For the benefit of growers or shippers who may be interested in installing vacuum cooling equipment, it seems desirable to include

the names of some of the designers and manufacturers of vacuum systems. This information is included for convenience, is not a complete list, and the mention of names does not imply any endorsement by the New York State College of Agriculture at Cornell University for any product, service, or design.

The first patent, No. 2,344,151 for a method and apparatus for treating perishable articles with vacuum was issued to Morris Kasser of Roseville and San Francisco, California in 1944. Subsequently Mr. Kasser obtained an additional patent, No. 2,651,184 in 1953 for a vacuum method and device for cooling produce. Many of the plants built and operated in California were licensed under these patents.

A patent, No. 2,684,907 was issued to Rex L. Brunsing of San Francisco in 1954 on the method of shipping lettuce and of preparing lettuce for shipment. This patent covers the use of the fibre board container.

In addition to these designers mentioned above, the following firms have engaged in building and designing parts or whole vacuum cooling installations.

Gay Engineering Corporation
2863 East 11th Street
Los Angeles 3, California

Associated Refrigeration Engineers
2100 E. Vernon Avenue
Los Angeles 11, California

Freezing Equipment Sales, Inc.
1405 North Duke Street
York, Pennsylvania

Automatic Steam Equipment, Inc.
710 North Fifth Street
Philadelphia, Pennsylvania

Jet Vacuum Cooler Corporation
Suite 1300
Market Street National Bank Bldg.
Philadelphia, Pennsylvania

Eastern Vacuum Cooling Inc.
1 West Lancaster Avenue
Ardmore, Pennsylvania

V. B. Hook and Company
10–13 Columbia State Farmers Mkt.
Columbia, South Carolina

Fuller Pump Company
Catasauqua
Pennsylvania

Graham Manufacturing Co., Inc.
415 Lexington Avenue
New York 17, New York

Ace Manufacturing & Welding Co.
Woodbury
New Jersey

Croll-Reynolds Engineering Company, Inc.
17 John Street
New York, New York

Vitavac Corporation
Anaheim, California

Contents

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